

IDENTIFICATION OF EMERGING RESEARCH TRENDS AND ISSUES IN MARITIME FACTORS

JAMES L. JACKSON AND LOUIS TIJERINA

Special Report

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NAVAL BIODYNAMICS LABORATORY
Box 29407
New Orleans, LA 70189-0407



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Task A Interim Report

**IDENTIFICATION OF EMERGING RESEARCH TRENDS
AND ISSUES IN MARITIME HUMAN FACTORS**

for the Program

**Support of Naval Biodynamics Laboratory Ship Motion
Research Program and Collaboration with University of New Orleans
Advanced Marine Technology Center**

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to

**Naval Biodynamics Laboratory
13800 Old Gentilly Road
New Orleans, LA 70189-0407**

by

**James L. Jackson
Louis Tijerina**

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**505 King Avenue
Columbus, Ohio 43201-2693**

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1. INTRODUCTION

1.1 BACKGROUND

The Naval Biodynamics Laboratory (NBDL) has a rich history as the principal U. S. Navy enterprise for conducting biomedical research on the effects of mechanical forces, both motion and impact, encountered aboard ships or aircraft on naval personnel. This biomedical research has included investigations of biomechanical, physiological, perceptual, and cognitive functions of naval personnel.

The University of New Orleans (UNO), located near NBDL and a long-time research partner, has recently established an Advanced Marine Technology Center (AMTC) to perform research, development, testing, and evaluation projects in support of U. S. Navy and commercial maritime interests. Both UNO and NBDL have the objective of collaborating on research projects of mutual interest. To facilitate this collaboration, Battelle has been contracted to identify research capabilities, current research and development (R&D) programs, and anticipated research needs for commercial and defense interests that might be supported by the to-be-developed NBDL/AMTC.

1.2 PROJECT OBJECTIVES

The purpose of this report is to identify human factors research capabilities, current R&D programs, and anticipated or emerging research needs for commercial and defense maritime interests (i.e., those within the U. S. Navy, U. S. Coast Guard, Maritime Administration, and other potential sources potentially associated with NBDL/AMTC at UNO). The goal of this identification process is to document critical human factors research issues and trends that may be suited to NBDL/AMTC's capabilities.

1.3 APPROACH

This identification process was made possible through a survey of individuals who either represent or are funded by:

- U. S. Coast Guard
- U. S. Maritime Administration (MARAD)
- U. S. Navy
 - U. S. Navy Sea Systems Command (NAVSEASYS COM)
 - Office of Naval Research (ONR)
 - NRaD
 - The Naval Postgraduate School
- Selected Academic Institutions in the United States
- The Danish Maritime Institute

A survey approach was selected as the means to gather information on emerging research needs and trends. Respondents were contacted either by telephone or facsimile transmission and were asked to fill out or give verbal response to the questions developed for this task. The survey items are presented in Table 1.

1.4 REPORT ORGANIZATION

The results of contacts with source groups is presented in Section 2. It is worth noting at this point that we believe that there are a number of research topics uncovered by our survey process that may be of interest to NBDL/AMTC. Specific research topics thought to be applicable for NBDL/AMTC capabilities are discussed in Section 3. Section 4 of this report features the list of research topics from Section 3 rearranged and prioritized to reflect and address the unique capabilities of NBDL/AMTC, and concluding remarks.

1.5 ASSUMPTIONS

Both NBDL and AMTC are in a state of flux at the time of this writing. NBDL is slated to be decommissioned in FY96, and the form and organization of the AMTC remains undefined. Given this level of uncertainty, we have made assumptions about the future NBDL/AMTC organization.

It is assumed, for instance, that ship motion research will continue to be a mainstay of NBDL. However, collaboration with the AMTC will enrich their capabilities to pursue work in the areas of crew systems ergonomics highlighted in this report. Finally, by direction of NBDL, impact research as distinct from ship motion research, is deliberately excluded from this report.

**TABLE 1. SURVEY ITEMS SELECTED TO IDENTIFY EMERGING
HUMAN FACTORS RESEARCH NEEDS**

Survey Items
1. What topics are currently being pursued in your R&D program?
2. What kinds of shipboard human factors engineering research needs to be conducted within the next 5 years (e.g., ship motion effects research, pharmacological interactions research, shipboard/bridge automation research, crew size/manning research)?
3. For the research needs you mentioned (and discussed), what facilities do you possess that would aid in their execution?
4. For the research needs you mentioned (and discussed), what facilities do you know about that would aid in their execution?
5. What do you consider to be the "top 3" areas of shipboard human factors research that need to be investigated?
6. Who would you recommend we contact to further our understanding of human factors research needs in commercial maritime and defense marine technology?

2. RESULTS OF SURVEY OF R&D PROGRAMS AND HUMAN FACTORS NEEDS

What follows are R&D programs and human factors needs identified by each of the organizations tapped for this program. The lists presented in this section are not to be taken as exhaustive, but rather are representative of current trends. The absence of research facilities descriptions should be taken to indicate no substantive responses to questions 3 and 4 in Table 1. The purpose here is to identify topics of concern within each organization.

2.1 U. S. COAST GUARD

Information on Coast Guard interests was obtained from the Battelle Human Affairs Research Center, Seattle, WA. This branch of Battelle has done an extensive amount of human factors research for the Coast Guard.

Current R&D efforts at the Coast Guard are addressing:

- Crew requirements for specific point-to-point voyages;
- Qualifications, training, and certification of mariners based on changes in technology (e.g., radar);
- Fatigue on commercial ships, involving assessments based on Stanford Sleepiness Scale, duty logs, subjective reports of sleep quality, and critical instance analysis;
- Assessment of computer-based evaluations as compared to paper-and-pencil batteries for testing mariner capabilities;
- Methods for increasing the quality of maritime casualty databases so that human factors contributions to accidents are included;
- Simulator effectiveness and fidelity;
- Viability of live-aboard situations;
- Electronic vs. paper charts.

Respondents who are involved with Coast Guard interests indicated several human factors areas that require research over the next 5 years. They include:

- Evaluation of the "one-man bridge" concept;
- The effect of the one-man bridge on ship safety ;
- Effect of one-man bridge on workload and monitoring demands;
- Interactions of fatigue effects and crew size as crew reductions are imposed;
- Human factors on high-speed (> 40 knot) cargo vessels.

2.2 U. S. MARITIME ADMINISTRATION (MARAD)

MARAD's R&D efforts, at the time of this writing, consist of a number of near-term research projects. They are general and include:

- Ship performance;
- Port infrastructure;
- Shipyard revitalization;
- Systems assessment.

These particular projects have been designed to assist shipbuilding, ship operations, ports and intermodal transportation, cargo operations, pollution prevention, and sealift readiness for the

U. S. Merchant Marine and the U. S. shipbuilding industry. These projects have as explicit goals the need to support the readiness of ships, merchant marines, and shipbuilding and repair capacities to sustain the United States during national emergencies and times requiring mobilization.

MARAD has indicated 3 large-scale research efforts to be undertaken within the next 5 years.

They encompass:

- The Ship Operations Cooperative Program, which is a collaboration of ship operators the Federal government that generates its own research agenda; the Program's specific human factors interests are fitness-for-duty, training, and bridge integration;
- A human factors research program with state and federal maritime academies; this program is currently addressing: the development of a maritime online bibliography of human factors materials; studies on the effectiveness of ship handling simulation training versus onboard training; standardization of ship handling simulation training curriculum; gender differences at sea; the assimilation of information affecting the mariner and his education/training; and a review of how the mariner fits into the bridge of the future;
- Vessel Piloting Cooperative Program with the American Pilots Association; the research agenda that this cooperative has adopted emphasizes the usability of portable computers by pilots to assist with navigation.

MARAD further indicated 3 areas within which human factors research is either lacking or is incomplete. Those areas involved:

- Investigation of methodologies to improve quality management of organizations (e.g., including, but not limited to bridge resource management);
- Correct performance monitoring and feedback to crew aboard ship;
- Person-machine integration.

MARAD is also collaborating with other Department of Transportation agencies to address the problem of operator alertness (cf. Freund, Knipling, Landsburg, Simmons, & Thomas, 1995). Loss of alertness is a concern to highway, rail, aviation, and maritime safety. MARAD has

supported fitness-for-duty test development suitable for the highly cognitive nature of ship operations. In addition, MARAD is working with the state marine academies to examine work hours and overtime policies, ergonomics, skills and task analysis, and other human factors issues that bear upon loss of alertness.

2.3 U. S. NAVY

Generally speaking, the U. S. Navy remains concerned with the disruption of shipboard tasks by motion sickness. They have begun funding research on a theory of motion sickness that emphasizes the role of postural instability as the cause of motion sickness (cf. Riccio & Stoffregen, 1991). This approach runs counter to the mainstream theory of motion sickness based on sensory conflict (Stoffregen & Riccio, 1991).

Several groups within the Navy were approached for this program. Their responses follow in this subsection.

2.3.1 U. S. Navy Sea Systems Command (NAVSEASYSCOM)

NAVSEASYSCOM is currently conducting R&D on:

- Various metrics, such as function analysis, function allocation, and task analysis to optimize shipboard manning;
- Anthropometry and biomechanical analysis to support human modeling;
- Crew performance during ship motion.

NAVSEASYSCOM identified a number of human factors areas and topics that will require investigation in the upcoming half-decade. Generally speaking, these topics comprise:

- Crewsize and manning;
- Shipboard automation, especially bridge automation);
- Decision aids and intelligent systems interface(s);
- Ship motion effects;
- The use of modeling, simulation, and virtual environments to assess the role of the person in the person-machine system;
- The Command Center of the future;
- Stress and fatigue effects on crew readiness;
- Human error and human reliability modeling.

2.3.2 Office of Naval Research (ONR)

ONR does not possess its own R&D facilities. Rather, it identifies research issues and funds research to such facilities as NRaD, government laboratories, public and private universities, and private industry.

The principal topical ongoing R&D areas identified for the current NBDL/AMTC program consist of:

- Complex mission planning and decision making;
- The extraction of critical information under complex and uncertain tactical conditions;

- The design and acquisition of human-optimized systems.

The following 3 items are those identified as crucial for ONR within the next 5 years:

- Information management and display (applications to C41, ASW, AAW, AsuW);
- Decision support and aid (e.g., collaborative decision making, adaptive architectures for C2, situation assessment, response selection, and such);
- Crewsize and manning (the imposition of forced downsizing, affordability).

2.3.3 Naval Research and Development (NRaD)

NRaD is currently involved in an international cooperative program that involves naval systems within the United States, Australia, Canada, New Zealand, and the United Kingdom. NRaD involvement represents U. S. concerns on human factors integration for naval systems. In 1994, bilateral meetings between these nations have identified 5 human factors areas at issue for future warship design. These 5 are:

- Design of principal operating areas for optimal flow of information to and from Command;
- Techniques for design and evaluation of human-computer interfaces;
- Specification of human factors requirements and acceptance criteria;
- Lean (austere) manning;
- Gender issues in ship design.

Follow-up bilateral meetings in 1995 narrowed down this list of topics in order to establish a collaborative effort for research. These meetings produced the decision to undertake research in the areas of:

- Enhanced information flow for Command teams and human-computer interfaces;
- Human factors in requirement definition and criteria for acceptance;
- Lean (austere) manning.

2.3.4 Naval Postgraduate School

The Naval Weapons Center (NWC) at China Lake, CA, is supporting, through research at the Postgraduate School, the U. S. Navy's initiative to develop a replacement for the F-14 airborne anti-air warfare weapon system, to be available by 2025. The NWC has undertaken the Advanced Tactical Airborne Weapons System - Fighter (ATAWS-F) project to guarantee support of this replacement initiative. Lind (1991) identified a number of human factors technology research issues that are critical to the ATAWS-F program, including:

- Vigilance;
- Visual display formats;
- G-induced loss of consciousness.

Additional research at the Postgraduate School currently deals with ship-to-ground or ship-to-ship target acquisition by means of direct vision. Direct vision refers to target acquisition through aircraft windscreens or through visual displays, rather than by aircraft sensors.

2.4 ACADEMIC INSTITUTIONS WITHIN THE UNITED STATES

Faculty at several U. S. universities were contacted to identify research issues that may have a bearing on future NBDL/AMTC efforts. These institutions included the University of Cincinnati, University of Connecticut, the Catholic University of America, and the University of Central Florida.

2.4.1 Motion Sickness Studies

Both the University of Cincinnati and University of Central Florida have researchers engaged in motion sickness research involving simulated motion environments. At Cincinnati, a moving room is utilized to produce motion of the visual surround (cf. Stoffregen, 1985). At Central Florida, flight simulators are exercised.

2.4.2 Fatigue Research

The University of Connecticut houses research ventures on fatigue (e.g., Paley & Tepas, 1994). Tepas (personal communication, June, 1995) indicated that there are no substantive data on the effects of motion on either work-rest cycles or time-on-duty.

2.4.3 Vigilance (Long-term Monitoring)

One research area that has been investigated by Catholic University is vigilance. Parasuraman (personal communication, June, 1995; cf. Malloy & Parasuraman, 1992; Parasuraman, 1987) identified many aspects of operational vigilance tasks that are unclear. They include:

- Motion effects on vigilance;
- Workload during task transition;

- Course of attentional performance on watch as number of targets (signals) increases over time;
- Appropriate display interface for providing perceptually available referents to alleviate memory load in long-term monitoring tasks;
- Aspects of automation that lead to operator complacency;
- Shifts from automated control of a task to full manual control and their effects on vigilance performance;
- Team monitoring to alleviate decrements.

2.5 THE DANISH MARITIME INSTITUTE

The final source contacted for this program was the Danish Maritime Institute. Their inputs provides a European outlook at maritime human factors research. Current Danish R&D programs involve:

- Decision support in damage control situations;
- Voyage planning;
- Crew resource management and training.

The 3 major areas identified by the Danish were:

- Crew-technology integration for performance in critical situations (e.g., damage control);
- Planning procedures and support systems;

- Technology for recording and analyzing operator behavior during and following operations (to provide data on operator performance during accidents).

3. HUMAN FACTORS RESEARCH TRENDS POTENTIALLY SUITABLE FOR NBDL/AMTC

3.1 MOTION SICKNESS RESEARCH AND THE RICCIO-STOFFREGEN THEORY

3.1.1 Problem

Motion sickness continues to be a concern to the Navy. While research has uncovered therapeutic methods for mitigating motion sickness symptoms, such as cognitive-behavioral therapy (Dobie & May, 1994), there remains an incomplete understanding of motion sickness (cf. Riccio & Stoffregen, 1991; Stoffregen & Riccio, 1991). In fact, several respondents contacted for this program identified motion sickness as a topic that should continue to be the focus of research efforts.

Riccio and Stoffregen (1991) have suggested an alternative to sensory conflict theory for explaining motion sickness. In their new theory, motion sickness is thought to be the result of an inability to maintain postural stability (stability of head and torso) during long-term exposure to motion environments. The crux of their theory is that it is the motion-induced disruption of postural control or the inability to adopt effective postural control strategies rather than the mismatch of sensation with expectation that is nauseogenic.

3.1.2 Scope

It has been demonstrated that visual motion (of the kind created in a moving room) leads to postural instability, such as the inability to maintain upright stance (Stoffregen, 1985). These demonstrations have been of a brief duration and have not led to motion sickness. Immediate work on the Riccio-Stoffregen motion sickness theory is planning to assess visually-induced simulator sickness. A central and initial goal of this line of research is to impose a level of optical motion that leads to postural instability and to see if this instability is associated with

symptoms of motion sickness (cf. Riccio & Stoffregen, 1991, p. 211-212; Thomas A. Stoffregen, personal communication, June, 1995).

According to Stoffregen (personal communication, June, 1995), the Navy is interested in this theory and has begun funding tests of it. Riccio and Stoffregen (1991, p. 234-236) have produced a list of hypotheses for research motivated by their theory of motion sickness. We believe that the hypotheses described by Riccio and Stoffregen are amenable to current NBDL capabilities (e.g., the ship motion simulator).

- Increases in passive restraint (which thereby minimize torso and head movement) should lead to decreased susceptibility to motion sickness symptoms in motion environments.
- General patterns of postural instability should be evident across participants in provocative motion environments.
- In motion environments involving low-frequency vibration, individuals may be able to shift the frequency of their postural control so that it is further from the range of imposed motions. This could lead to the exhibition of jerky or intermittent control behaviors.
- One point that is raised by Riccio and Stoffregen is the prophylactic nature of lying down during task performance in motion environments. Lying down allows for a degree of postural stability in motion environments. It is, therefore, possible that shipboard tasks normally disrupted by sick crew might be performed successfully in motion environments if the crew were allowed to lay down during the task.
- A piece of research not discussed by Riccio and Stoffregen that is potentially relevant to NBDL capabilities and ultimate maritime application involves cognitive-behavioral therapy. The cognitive-behavioral technique for mitigating motion sickness (May, 1991) has as one of its goals the establishment of a counseling regimen designed to allow motion-sensitive crew to be more relaxed in motion environments. Being relaxed can lead to more effective (adaptive) postural control strategies (Riccio & Stoffregen, 1991). It is possible that the therapy may actually promote relaxed postures, and that it is these relaxed postures that allow crew to resist motion sickness and return to duty.

3.1.3 Benefit

The tenor of research suggested by Riccio and Stoffregen is explicitly theoretical. However, it is hoped that theoretical advances may lead to operational applications. If the data are positive with respect to successful workstation performance when lying down, that in itself may suggest that certain shipboard tasks, workstations, and displays (to be determined through research) should be redesigned to allow for performance by supine crew.

Research in the NBDL/AMTC Ship Motion Simulator (SMS) may also identify effective postural control strategies with respect to the kind of motion imposed upon crew. Also, research may uncover specific motion profiles that exacerbate postural instability aboard ship. This research may lead to the establishment of procedures for task accomplishment during certain levels of pitch, roll, and heave.

3.2 VIGILANCE (LONG-TERM MONITORING)

3.2.1 Problem

Vigilance, also referred to as sustained attention, is important for the successful performance of a number of operational tasks. However, as time on watch progresses, increasingly more target events or stimuli are missed by operators. This is especially true if human operators monitor computer-based displays (cf. Warm, 1993). In addition, humans are typically unable to assess their own level of vigilance during watches. Failures of vigilance have been cited as contributing factors to a broad range of operational incidents, from the accident at Three-Mile Island (Wiener, 1984) to motorcycle-automobile collisions at intersections (Hancock, Hurt, Ouellet, & Thom, 1986). Theoretical understanding of vigilance remains incomplete (cf. Loeb & Alluisi, 1984) and countermeasures to operational decrements are still being sought (Mackie, 1987). In particular, there are only a few studies on the effects of motion on vigilance (Hancock, 1984).

3.2.2 Scope

Vigilance has been identified as a critical research topic within the U. S. Navy (Lind, 1991). Specifically, Lind has indicated that research is needed to produce or contribute to the development of:

- technological capabilities for monitoring aircrew vigilance and either alerting the aircrew to their reduced vigilance or taking over aircraft control during those periods of lowered vigilance;
- a set of procedures for the automation of critical monitoring tasks without diminishing aircrew vigilance;
- the means to preserve operator alertness on lengthy missions and assignments (This harkens back to the longstanding demand for countermeasures to operational vigilance decrements [e.g., Mackie, 1987]).

Raja Parasuraman (personal communication, June, 1995), in response to the current program, has identified several general, yet important lines of vigilance research.

- Recent research strongly suggests that vigilance tasks, while rather boring, impose a high level of workload upon human operators (see Warm, 1993, for a summary of this research). The course of workload during task transition from inactivity to combat is, however, unknown (cf. Warm, 1993, p. 156).
- What is the course of attentional performance in operational settings when the vigilance task transitions from low signal demand to high signal demand (e.g., an air traffic control task that transitions from few aircraft to monitor to increasing numbers of aircraft on screen)?
- Decreases in perceptual sensitivity to signals on lengthy watches have been associated with high memory load tasks (Parasuraman, 1979). If it is indeed the case that many operational vigilance tasks place a high demand on memory, the questions then become what is the nature of the memory demand? Does the demand involve short-term or long-term memory? As a countermeasure for those decrements associated with memory demand, what is the appropriate design of a memory aid to improve performance? Can automation play a hand in aiding human operators on watch (cf. Lind, 1991)? What is an

appropriate display interface for providing perceptually available referents so as to alleviate memory load in long-term monitoring tasks?

- Increases in automation are beginning to create operational situations where human operators and automated systems serve as joint monitors of critical events and processes (Parasuraman, 1987). Humans are asked less to control system operation on a point-by-point basis. Rather, humans are finding themselves responsible for monitoring the (usually highly reliable) automated system and intervening only when the system has failed. Research is needed to determine what aspects of automation, or what specific kinds of automation, lead to operator complacency (Malloy & Parasuraman, 1992). The goal is not so much to reduce workload, but to optimize it.
- The effects of shifts from automated control of a task to full manual control on vigilance performance are unknown. What is the nature of the transition (e.g., is it necessary to warn operators of an impending shift from automated to manual control)?
- There is equivocal data on team monitoring to alleviate decrements (only Bergum and Lehr (1962) examined the effects of psychophysical variables on team monitoring, so it is unknown what kinds of display interfaces may support team monitoring).

3.2.3 **Benefit**

The research discussed by both Lind (1991) and Parasuraman (personal communication) has immediate applications to operational situations. Lind's topics were specific to aircrews, and as such may not be amenable to NBDL capabilities. Although Parasuraman identified each topic generically, each of his items of research can be made specific to shipboard operations. According to Hancock (1984), there is a dearth of research on vigilance effects in vibrating or moving environments. NBDL is well-suited to address vigilance in motion environments.

3.3 FATIGUE

3.3.1 Problem

Several respondents contacted for this program identified fatigue as a research concern for surface fleet and maritime interests. NBDL efforts previously have considered the effects of motion on fatigue. However, the interest in fatigue has not waned. A recent special issue of the journal *Human Factors* (June, 1994) was devoted to fatigue. Topics covered ranged from conceptualizations of fatigue and its measurement (psychological vs. physiological distinctions; subjective vs. objective assessment; redefining fatigue in terms of work-rest cycles, etc.) to research issues that face human factors practitioners as we move into the 21st Century. In particular, Tepas (personal communication, June, 1995) indicated that there was a lack of understanding about the effects of motion on work-rest cycles, crew rotations, and time-on-duty. Furthermore, Coast Guard research is currently aimed at addressing:

- fatigue effects on commercial ships involving a survey of current practices;
- the interaction of fatigue and crew size and the impact on safety;
- changes in fatigue as crew size decreases.

3.3.2 Scope

Rosekind, Gander, Miller, Gregory, Smith, Weldon, Co, McNally, and Lebacqz (1994) have highlighted and discussed several measures of fatigue that have been employed for the NASA Ames Fatigue Countermeasures Program. These measures include:

- background and self-report indices (e.g., questionnaires, logbooks, etc.);

- physiological variables (e.g., core body temperature, electroencephalograms, electro-oculographs, and electromyographs);
- performance measures, (e.g., vigilance tasks).

For Coast Guard fatigue research, dependent measures of fatigue have included:

- subjective reports of sleep quality;
- Stanford Sleepiness Scale
- critical instance analysis

3.3.3 Benefit

These indices appear to be amenable to evaluation in motion environments in order to address Tepas's concern on the dearth of research on fatigue in motion environments. Information generated by this line of research can make a substantial contribution to the development of work-rest cycles and time-on-duty requirements based on the degree of motion involved.

3.4 MANNING AND CREWSIZE REDUCTION

3.4.1 Problem

Respondents to the survey for this program noted that efforts are needed to establish a model for determining shipboard crew complement (see Table 1). A concern throughout the defense-related and commercial maritime industries is the need to reduce the number of shipboard staff (Bost, Mellis, & Dent, in press). For instance, the Japanese have crews with as few personnel as

11 (Lee & Sanquist, 1993b). Technology advances and the need for reduced budgets are driving the movement for reduced crewsize.

3.4.2 Scope

Lee and Sanquist (1993b) have examined manning modeling efforts from several operational settings, including commercial maritime operations and have proposed that manning models should address:

- the ability of ship personnel to meet workhour requirements specified under regulation;
- the ability of ship personnel to manage emergencies;
- the effect(s) of crew reductions, engendered by introduction of automation, on navigation performance;
- the ability of a reduced crew to meet the demands of both scheduled and unplanned maintenance.

3.4.3 Benefit

Computer-aided design (CAD) approaches to manning may be of direct benefit to ship operations.

3.5 STUDIES OF EQUIPMENT USABILITY IN MOTION ENVIRONMENTS

NBDL has conducted research on task performance in motion environments. For example, Morrison, Dobie, Willems, Webb, and Endler (1991) evaluated performance aboard an FFG-7 class frigate outfitted with five roll stabilizers. They assessed performance under no motion, roll stabilized, and non-roll stabilized conditions on four-choice reaction time, memory and search, and critical instability tracking. Research of this kind suggests the potential for further

investigations of the usability of specific pieces of shipboard equipment during motion conditions.

What follows are two examples of directions for research on equipment usability under motion conditions, one specific, and one rather general.

3.5.1 Automated Radar Plotting Aids (ARPA)

3.5.1.1 Problem - Lee and Sanquist (1994) pointed out that automation on ship decks began with enhancements to radar displays and technologies. A recent example of perceptual augmentation technology has been automated radar plotting aids (ARPA). By perceptual augmentation is meant technologies that allow mariners to perceive objects or relationships that would ordinarily go unnoticed (i. e., under direct observation or current level of technology). ARPA radars display a wide range of textual and graphical information, including relative and absolute speed and direction of any surface vessel within radar range. Furthermore, ARPA radar can also calculate the distance and time of closest approach and provide a number of trial maneuver functions that can lead to future trajectories of the ships, given proposed speed and course changes. ARPA may use text as the format for this information, or it may use icons that represent safety zones around the ships.

ARPA has been mandated for upwards of twenty years and it does ease the tracking and avoiding of other ships, but it is still possible for ARPA data to be misinterpreted (Lee & Sanquist, 1994). Problems that mariners have today with ARPA are not the result of novelty with the system, but rather are evidence of chronic difficulties in ARPA interpretation.

3.5.1.2 Scope - Lee and Sanquist (1994) indicate that there are no data from any systematic evaluation (either analytical or empirical) of radar-based errors. There are no taxonomies of error types associated with ARPA technologies. A comparison of ARPA designs is needed so that an optimum ARPA display interface can be selected. This assessment should also include

display usability under conditions of ship motion. Once an ARPA interface is identified, a training strategy for the ARPA needs to be generated.

3.5.1.3 Benefits - Respondents contacted for this program almost universally named bridge or shipboard automation as a critical research area over the next 5 years (and beyond). ARPA are just one form of bridge automation. Lee and Sanquist (1994) have distinguished several specific questions that ARPA research needs to address. Moreover, each of the questions identified for ARPA research requires evaluation in both motion and non-motion situations.

3.5.2 Automation and High Technology Bridge

3.5.2.1 Problem - Automation has been mentioned elsewhere in this report as a concern for maritime interests (e.g., Section 3.2, Section 3.5.1). ARPA serve as a specific example of bridge automation and its coincident human factors issues. There are further examples of bridge automation (e.g., Collision Avoidance Systems for ship navigation; Lee & Sanquist, 1993a), and an immediate concern that has been raised with respect to automation is the problem of increased operator workload. Operator workload associated with increments in bridge automation may be wholly exacerbated in motion environments.

3.5.2.2 Scope - Sanquist, Lee, Mandler and Rothblum (1993) designated several general aspects of automation that should be of interest to the entire maritime community. We present their list of topics, except that we have recast them in light of possible motion effects.

- **Cognitive impact of automation** - increments in automation may radically shift operator information processing resources and the execution of specific job functions; these processing demands and job function requirements may vary significantly with respect to diverse sea states (e.g., display monitoring and processing demands imposed by visual shear during severe pitch, roll, and heave).
- **Training in support of automated technologies** - a training strategy developed for a low- or non-motion environment may earnestly differ from training suited for motion.

- **Development of design guidelines** - user interface development should strive to adhere to human factors principles, and those principles may need to differentiate between motion and non-motion situations.
- **Alarm systems** - alarms need to alert and to convey a means to mitigate the emergency; alarm coding may need to be specific to the degree of motion imposed on the vessel during the emergency (but this must be balanced with the degree of workload imposed on operators and crew by multiple levels of information coding).
- **Information distribution** - there will be an increasing need to present task-relevant data at multiple workstations and the quick availability of information at multiple workstations will become more important as crew downsizes occur; however, the demands of multiple workstations should be assessed in motion situations to perhaps specify the optimum number of workstations to be monitored during varying levels of sea motion.
- **Electronic navigation aids** - See Section 3.5.1. for a specific example.

3.5.2.3 Benefit - The kind of bridge automation research that, presumably, NBDL/AMTC would address would be able to not only address issues nominally raised by Sanquist et al. (1994), but also to recouch those issues with respect to motion environments. It is hoped that the NBDL/AMTC research ventures would be able to provide refined answers to questions of bridge automation.

3.6 INTERACTIONS OF DRUGS AND/OR ALCOHOL WITH MOTION

3.6.1 Problem

It goes without saying that alcohol consumption can have disastrous consequences for ship operations. For example, in early 1989, the oil tanker Exxon *Valdez* ran aground in Prince William Sound, Alaska. Alcohol use by the captain has been named as a contributing factor to the accident. Also, increased consumption of alcohol in the evening prior to exposure to motion

environments can lead to heightened motion sickness susceptibility (Dobie & May, 1994). These are only two examples of the negative effects of alcohol in motion environments.

Drug use on ship may also be a concern for mariners, especially those that are controlled substances. Drugs can be classified along 3 lines:

- Commercially available (e.g., over-the-counter medications, caffeine in soft drinks, nicotine in cigarettes, etc.);
- Prescription medications (e.g., penicillin, codeine, etc.);
- Controlled substances (e.g., crack cocaine, heroin, etc.).

3.6.2 Scope

Research on the interaction effects of drugs and/or alcohol and motion are not well understood. Research on drugs and motion may take the shape of the examination of task performance either at sea or in the SMS, or the examination of motion profiles under drugged conditions.

3.6.3 Benefit

Research of this nature will have direct bearing on the understanding of the interplay of drugs with motion. Efforts in this vein will involve behavioral and biological scientists, as well as engineers and health professionals.

3.7 DAMAGE CONTROL AND EMERGENCY RESPONSE

3.7.1 Problem

Pleasure ships such as cruise ships are notorious in the commercial maritime industry for having inadequate damage control training, procedures, and ship design countermeasures. That damage control can be critical aboard cruise ships was recently reinforced by the electrical fire that disabled the *Celebration*. This fire fortunately only resulted in the vessel being dead in the water; there were no crew or passenger casualties. However, there is a great deal known about damage control and ship survivability in the Navy that is ripe for technology transfer to this sector of the commercial marine community.

3.7.2 Scope

The AMTC and NBDL appear to be highly suited to a comprehensive approach to integrating damage control into cruise ship design and operations. Damage control blends ship design and equipment design with crew training, management, and procedures to lead to effective control and containment of fire, flooding, smoke, and other hazards. A great deal of research and practical experience in the Navy surface fleet could be made available via technology transfer in to the commercial fleet, especially for cruise or pleasure ships. Some possible approaches might be the following:

- Naval architects can examine the ship design principles that enhance damage control and ship survivability. This can include hull designs, strength of materials, ventilation systems configurations and fittings, damage control locker placement and equipment, and so forth.
- Human factors staff, working in conjunction with damage control or surface ship safety subject matter experts, can examine how best to transfer damage control training and procedures from naval applications to commercial marine applications.

- Naval research into damage control and ship survivability decision support (e.g., Tijerina, Stabb, Miller, & Buxton, 1991) should be reviewed and assessed for applicability to commercial maritime applications. For those decision aids that appear suitable, human factors, operations research, and computer science specialists could work together to develop software and hardware systems, as well as manual aids that assist damage control decision makers in allocating limited resources in the face of competing demands.

3.7.3 Benefits

This research area provides an excellent opportunity for technology transfer between the U.S. Navy and the commercial maritime industry. As the bridge between these two application areas, the AMTC in collaboration with NBDL appears to be well poised to take the lead in this area. Enhancement of damage control and containment in the commercial maritime fleet, especially aboard cruise ships that transport many passengers, can provide substantial benefits in terms of maritime safety.

3.8 SHIP DESIGN ERGONOMICS EVALUATION

3.8.1 Problem

The 1980's saw an outpouring of efforts to better ensure the applications of human factors and human engineering criteria to ship and ship system design (Malone, 1989; Malone, Feaga, Andrews, & Kopp, 1983; cf. Tullis, Bied Sperling, & Steinberg, 1986). From these inroads, we have witnessed ventures such as the assessment of the Coast Guard's 47-ft motor lifeboat (Holcombe & Webb, 1991), conducted at NBDL.

Respondents contacted for this program echoed the sentiment that ship design ergonomics evaluation must be kept at the forefront of maritime human factors R&D.

3.8.2 Scope

There are a number of techniques available that take into account human factors and human engineering criteria. They can be used to drive ergonomic evaluations of ship design. Several of them follow.

- **MIL-H-46855B** - This document establishes and defines the requirements for applying human engineering precepts to the development and acquisition of military systems, equipment, and facilities; these requirements include the kinds of work to be conducted to support a human engineering effort integrated into the total system engineering and development effort; system analysis, task analysis, system design, equipment and facilities design, testing, documentation, and reporting are all addressed in this document.
- **MIL-STD-1472D** - This document establishes general human engineering criteria, principles, and practices to be applied in the design of systems, equipment and facilities in order to: (1) achieve required performance by operator, control, and maintenance personnel; (2) minimize training time of personnel; (3) achieve required reliability of personnel-equipment combinations (i.e., person-machine interactions); and (4) foster design standardization within and among systems.
- **MIL-STD-498** - This standard defines a set of activities and documentation suitable for the development of both weapon systems and Automated Information Systems. Relationships to human factors criteria are established in the standard in terms of: (1) understanding of user needs; and (2) nature of personnel using specific systems (human engineering criteria).
- **HFTEMAN** - Human Factors Testing and Evaluation Manual.

3.8.3 Benefit

The current program has reinforced the demand for ship design ergonomics evaluations. The benefits of NBDL/AMTC's continued involvement in these endeavors includes refining ship facility layout and continued marshalling of NBDL/AMTC capabilities.

3.9 COMPUTER-AIDED DESIGN (CAD) TOOLS FOR INTEGRATION OF CREW REQUIREMENTS INTO SHIP DESIGN

3.9.1 Problem

Current ship design begins with high level specifications for ship stability and speed. Naval architects then select a hull design and iteratively trade off design alternatives to arrive at a feasible, responsive design. To date, crew performance considerations have not been adequately considered in the ship design process. This has sometimes led to crew performance degradation that compromised mission success and required ship design alterations. What is needed are computer aided design (CAD) tools that could formally represent crew requirements so they may be integrated into ship design. It is motivated by the premise that a ship is ultimately only as capable as the crew aboard.

3.9.2 Scope

Previous work in this area has focussed on the following approaches.

- **Link analysis and Multidimensional Scaling (MDS):** This is a method to show the frequencies associated with human-to-human and human-to-machine interactions (Chapanis, 1959). Human-to-human interactions may involve face-to-face dialogue between crew members; human-to-machine interaction may involve crew member use of a display or data entry workstation. This type of analysis is useful for layout and arrangement of crew members and machines. Tullis et al. (1986) illustrated the use of multidimensional scaling (MDS) to facilities layout. MDS is a method for transforming a matrix of pair-wise distances or proximities among a set of N objects into a spatial representation. In the ship design context, MDS approaches can be used to illustrate initial equipment or workstation configurations that maximize proximity between frequently interacting human and machine components in the system. Siegal, Wolf, and Pilitsis (1982) illustrate the MDS approach to an office layout. Pulat (1984) developed an alternative to MDS in which the most frequently interacted-with component is placed in the center of a space and other components are positioned about this with consideration to the space requirements of each component. Further evolution of such approaches may be of great benefit to the ship design community.

- **Cluster Analysis of Shipboard Functions and Layout Implications.** Hierarchical cluster analysis is a method by which matrices generated from a link analysis or other rule of relatedness (e.g., sequential dependencies) are analyzed in algorithms that group objects like shipboard functions into clusters in a hierarchical manner. The most closely related functions or spaces are clustered together, and the hierarchical nature of the analysis allows sets of functions to be clustered at higher levels (cf., Tullis et al., 1986). Such computer-aided techniques can be useful to the naval architect in the integration of crew factors into ship design.
- **Operations Research Algorithms for Crew Assignment:** A number of approaches from operations research and industrial engineering may be applied to human factors requirements integration via computer-aided design of ships. These include:

Linear programming (LP) applications. LP applications such as the assignment problem may be investigated to allocate crew to ship spaces so as to minimize (e.g., crew motion-induced performance degradation) or maximize (e.g., likelihood of mission success) an objective function (Tijerina, 1994). An objective function is specified along with a system of constraints and the LP algorithms work to identify an optimal (though not necessarily unique) solution.

Scheduling and Line Balancing Algorithms and Sequential Network Modeling in Ship and Equipment Design. NBDL has supported research into scheduling heuristics that may be used to assign crew to shipboard tasks to assess crew size requirements (Tijerina & Treaster, 1991). The Office of Naval Research (ONR) has also sponsored research into application of line balancing algorithms to crew tasking or workstation design. Pulat (1985) presents an algorithm called WOSTAS that incorporates different human abilities required of tasks and ability levels of crew members to assess alternative task assignments to crew members and the impact of number of crew members or workstations to complete a shipboard operation. Finally, Tijerina and Treaster (1991) illustrate the use of discrete sequential network simulation to assess shipboard operations such as weapon loading in order to estimate completion times and alternative procedures and manning levels. Perse, Callahan, and Malone (1991) recently applied a simulation program called SIMWAM to address man and machine functional allocations for integrated survivability management aboard an AEGIS class combatant. Such approaches merit further development to support ergonomic design of ships, shipboard equipment, and shipboard procedures.

Other computer-aided design approaches. Other approaches have been introduced into the literature that merit further research. For example, Kanter and O'Brien (1989)

presented a review of methods applied to submarine layout that included many of the methods just mentioned as well as a population density index (PDI) that attempts to address the problem of crowding in ship design.

In general, the development and implementation of such computer-aided design tools may be pursued by a multidisciplinary team that includes behavioral scientists, mathematicians and statisticians, software engineers, naval architects, and operational subject matter experts. The results of such collaboration will be to provide the benefits described below.

3.9.3 Benefits

Crew-centered performance degradations can have adverse consequences in terms of maritime safety and efficiency. Computer-Aided Design (CAD) tools can provide a means to apply to ship design the results of research into motion-induced crew degradations (motion sickness; cognitive decrements, motion-induced interruptions, motion-induced fatigue), crew-to-crew and crew-to-machine link analysis, shipboard functions analysis, and the like. Thus, such tools provide a means to meaningfully apply human-centered research. Development of such tools also has the benefit of providing a focus to human-centered research to applications that support the ship design process.

3.10 DEVELOPMENT AND APPLICATION OF HF TASK ANALYSIS AND SHIPBOARD OPERATIONS ANALYSIS FOR SHIPBOARD OPERATIONS

3.10.1 Problem

Even if computer-aided design tools are available, they require carefully collected data upon which to operate. This entails task analysis and shipboard organizational analysis (e.g., process flows, communications links, etc.). Such data collection may benefit from enhanced methodologies and existing methodologies must be implemented and carried out. This is a potentially fruitful area for AMTC and NBDL collaboration.

3.10.2 Scope

This research area can be conveniently broken into two separate activities.

- Execution of task analysis and shipboard operations analysis. This activity may entail ship rides during which video tape, audio tape, or other automated means are applied to capture task analytic data and shipboard operations data. In addition, human factors staff may make observations and report on analysis of, e.g., human abilities associated with a particular shipboard duty by means of human abilities scales applied through interviews with crew members (e.g., Fleishman & Quaintance, 1984). An alternative might include data collection in a mockup of a to-be-developed bridge, or other shipboard area.
- Development of enhanced methods of task analysis and shipboard operations analysis. New methods are required to enhance the efficiency of data collection as well as the quality of the data that is collected. For example, Kanter and O'Brien (1989) describe a video technique called the Expert Vision System™ that uses advanced image processing algorithms to analyze activities in a control room mockup. New methods in cognitive task analysis will be needed as the activities performed aboard naval and commercial marine vessels become increasingly more cognitive in nature and less amenable to physical descriptions.

3.10.3 Benefits

The development of a ship design that is responsive to crew requirements presupposes that such requirements have been defined. Task analysis and operations methods are the means by which such requirements can be articulated, preferably in a manner that is compatible with computer-aided design tools. Thus, the ATMC in collaboration with NBDL can provide a substantial benefit to the shipbuilding communities (both commercial and naval) by implementing methods and approaches to task analysis and operations analysis that exist as well as furthering the state-of-the-art in terms of methodology.

3.11 RIDE QUALITY FOR GROUND TRANSPORTATION

A final topic for consideration in this report is the necessity for ride quality research in ground transportation industries. While the domain may be atypical for NBDL/AMTC, nonetheless we believe that NBDL/AMTC might be able to make a contribution to improved vehicular design based on the kinds of motions experienced by operators and passengers.

3.11.1 Problem

There are opportunities for the evaluation of motion effects in ground transportation modes (e.g., high-speed rail; cf. Sheridan, Lanzilotta, & Yin, 1993). Haas (1989) detailed an experimental evaluation of the impact of whole-body vibration in lateral, transverse, and vertical dimensions on several boundaries (fatigue, comfort, and exposure) indicated by the International Standards Organization (1985). She uncovered a number of differences in whole-body vibration between track types, crew stations, terrains, and vehicle speeds she employed. What is most revealing about Haas's research for the purposes of the current program is her demonstration of the need for assessment of various aspects of ride quality in ground transportation. In fact, Haas (1989) indicated that the bulk of the previous research on the effects of whole-body vibration in ground transportation has not taken advantage of rigorous experimental design methodologies (reports of speed variables, crew position within the vehicle, statistical analyses, etc.).

3.11.2 Scope

Research of this nature would presumably begin with simulator investigations. NBDL/AMTC would need either to develop their own ground transportation simulator, modify existing motion simulator equipment, or work with outside agencies, such as the University of Iowa Driving Simulator.

3.11.3 Benefit

The benefits of ride quality research for ground transportation modes can provide information to several industries, such as high-speed rail and the automotive and trucking industries on the nature of motion forces within a ground transportation vehicle. Furthermore, rigorous experimental assessments conducted at NBDL/AMTC can delineate the effects of whole-body motions on operators and passengers and contribute to the establishment of guidelines regarding crew positioning and optimum vehicle speeds relative to terrain.

4. FUTURE DIRECTIONS

4.1 SUMMARY

The previous sections have presented a representative survey of maritime and surface fleet human factors research trends and issues and a detailed examination of 11 topical areas which might be amenable to NBDL/AMTC. The plan of this technical report was to first scan a number of maritime human factors interests and present them in a fashion that serves simply to identify them. Over 25 human factors issues were introduced in Section 2. Some of these were very general, whereas others were much more specific in terms of content for research direction. In Section 3, 11 topical areas were filtered from among the larger list to form a grouping that, we believe, are better suited to NBDL/AMTC. These research areas include:

- Motion Sickness;
- Vigilance in both motion and non-motion environments;
- Motion and fatigue;
- Ship design ergonomics evaluation;
- Equipment usability in motion situations;
- Drug and/or alcohol interactions with motion;
- Human factors task analysis and shipboard operations analysis;
- Manning and crew size reduction;

- CAD tools for integrations of crew requirements into ship design;
- Damage control and emergency response;
- Ride quality in ground transportation.

4.2 RECOMMENDATIONS

The development of a research strategy for the AMTC should take an entrepreneurial approach. With such an approach, an organization looks at what it currently has to offer, i.e., its capabilities. Then the needs of the market are surveyed. A match between organization capabilities and market needs then form the basis of a marketing plan. If there is no match between a market need and an organization's capabilities, then further decision making is undertaken to determine whether or not that is an area the organization ought to pursue. If so, then technology investment plans are drawn and executed. Technology investment in this sense means investment not only in technology or facilities that enable the organization to pursue this new area but also investment in new hires that bring expertise needed for the new area of business.

At the present time, the AMTC and NBDL are in a state of flux. No organizational chart has been finalized and approved. The status of NBDL in the national base closure and realignment process is subject to frequent changes. There is no consensus on what types of capabilities the AMTC's human systems division might muster from NBDL or other sections of the University of New Orleans outside of the Institute for Naval Architecture. In fact, agreement that human factors should be part of the AMTC's focus is still debated. Thus, it has not been possible for the authors to characterize what the capabilities of the AMTC might be in the area of human factors.

In order to develop the outline of a research program that the AMTC might pursue, then, it was necessary to make many assumptions. For example, it was assumed that ship motion will remain a central theme of NBDL research. It was assumed that NBDL will continue to make use of

a central theme of NBDL research. It was assumed that NBDL will continue to make use of multi-disciplinary teams of behavioral scientists, engineers, mathematicians, and software programmers to achieve research objectives. It was assumed that the University of New Orleans Department of Psychology will participate in the AMTC and bring to bear a range of faculty expertise that spans the topical areas currently of interest in the commercial and defensive marine environment. Based on these assumptions, the authors have identified five areas from Section 3 that we believe deserve NBDL/AMTC's attention within its first 1-3 years of existence at UNO. In descending order of priority, the following topics are suggested as a research program that matches AMTC capabilities and the needs of the maritime and naval communities:

- Motion and fatigue research;
- Motion sickness research involving the Riccio-Stoffregen theory;
- Research on drug and/or alcohol interactions with motion;
- The application of CAD tools for integrations of crew requirements into ship design;
- Research on damage control and emergency response.

It must be noted that this list was reached with respect to the assumptions that were made for this program. These may be considered idiosyncratic and can, of course, be changed if NBDL deems it appropriate. However, it is a start on what is hoped to be the bright future of an organization committed to enhancing maritime and naval defensive interests in the areas of safety, efficiency, and effectiveness.

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